

Comparison of diagnostic accuracy, time dependency, and prognostic impact of abnormal Q waves, combined electrocardiographic criteria, and ST segment abnormalities in right ventricular infarction

Manfred Zehender, Wolfgang Kasper, Elisabeth Kauder, Martin Schönthaler, Manfred Olschewski, Hanjörg Just

Abstract

Objective—To determine the diagnostic and prognostic impact of abnormal Q waves in comparison to or in combination with ST segment abnormalities in the right precordial and inferior leads as indicators of right ventricular infarction during the acute phase of inferior myocardial infarction.

Design—Prospective study of a consecutive series of 200 patients with acute inferior myocardial infarction with and without right ventricular infarction.

Setting—Department of internal medicine, university clinic.

Results—Right ventricular infarction was diagnosed in 106 (57%) out of 187 patients from the results of coronary angiography, technetium pyrophosphate scanning, and measurement of haemodynamic variables or at necropsy, or both. In the acute phase of inferior infarction ST segment elevation ≥ 0.1 mV in any of the right precordial leads V4–6R was the most reliable criterion for right ventricular infarction (sensitivity, 89%; specificity, 83%). Abnormal Q waves in the right precordial leads, the most specific criterion (91%) for right ventricular infarction, were superior to ST segment

elevation in patients admitted >12 hours after the onset of symptoms. Both ST segment elevation in leads V4–6R (increase in hospital mortality, 6.2-times; $P < 0.001$; major complications, 2.3-times; $P < 0.01$) and abnormal Q waves (2.3-times, $P < 0.05$; 1.8-times, $P < 0.05$) on admission were highly predictive of a worse outcome during the in hospital period. In the presence of inferior myocardial infarction previously proposed combined electrocardiographic criteria were not better diagnostically or prognostically than ST segment abnormalities and abnormal Q waves alone.

Conclusions—During the first 24 hours of inferior myocardial infarction ST segment elevation and abnormal Q waves derived from the right precordial leads are complementary rather than competitive criteria for reliably diagnosing right ventricular infarction, both indicating a worse in hospital course for the patient. In this they are better than any other previously proposed combined electrocardiographic criteria in diagnosing right ventricular infarction. Right precordial leads should be routinely monitored in acute inferior myocardial infarction.

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Abteilung für
Kardiologie, Innere
Medizin III,
Universitätsklinik
Freiburg, Freiburg,
Germany
M Zehender
W Kasper
E Kauder
M Schönthaler
H Just

Abteilung für Med
Biometrie und
Informatik,
Universität Freiburg,
Freiburg, Germany
M Olschewski

Correspondence to:
Dr M Zehender, Innere
Medizin III,
Universitätsklinik Freiburg,
Hugstetterstrasse 55, 79106
Freiburg, Germany.

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Table 1 Diagnostic impact of electrocardiographic criteria for diagnosing right ventricular myocardial infarction

Electrocardiographic criterion	No of patients	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Reference no
<i>Right precordial electrocardiogram leads (V1–6R)</i>					
ST elevation:					
V3R > 0.05 mV	43	79	68	—	19
V3R > 0.1 mV	110	59	90	89	14,15
V4R > 0.05 mV	181	81	76	75	19,22,23
V4R > 0.1 mV	255	80	88	87	18,23,24,26,30
V5R > 0.1 mV	110	72	88	86	14,24
V6R > 0.1 mV	110	67	90	88	14,24
V4–6R > 0.1 mV	33	90	91	82	16
Q wave					
V3R	43	37	87	83	14
Q/QS V4R	71	85	59	—	19,23
QS V3–4R	28	78	100	94	23
<i>Left precordial electrocardiogram leads (V1–6) and standard leads (II,III)</i>					
ST elevation:					
V1 > 0.05 mV	115	38	40	27	19,40
V1 > 0.1 mV	183	28	65	47	16,21,24,40
V2 > 0.05 mV	115	33	18	20	19,40
V2 > 0.1 mV	105	20	38	19	16,18
ST elevation V2/ST depression aVF $< 50\%$	68	79	91	82	41
ST elevation > 0.1 mV:					
In II + III/II > 1	24	63	88	91	15
In III + III/II > 1	24	65	57	79	15

During recent years interest in right ventricular infarction as a complication of inferior myocardial infarction has spread beyond the deleterious effects on outcome.¹⁻³ Diagnostic approaches for assessing right ventricular infarction include physical examination,^{4,6} echocardiography,^{4,6} first pass^{7,8} or equilibrium radionuclide ventriculography,^{9,10} technetium pyrophosphate scanning,^{10,11} and haemodynamic measurements^{5,6,12,13} but have increasingly focused on electrocardiography as the most simple and readily available diagnostic tool.¹⁴⁻²⁵ Therefore, an increasing number of electrocardiographic criteria for right ventricular infarction have been proposed, including ST segment elevation or depression or abnormal Q waves in the right precordial, inferior, or left anterior leads either alone or in combination. Although we and many other working groups reported on the diagnostic accuracy of these criteria (table 1),^{24,26} there are no com-

parative studies evaluating more than three of the criteria in the same patient population and little is known about the time dependency of these criteria in the acute and subacute phase of inferior myocardial infarction.

The prognostic impact of right ventricular infarction as shown by electrocardiographic criteria has been emphasised. Our study and that of Andersen *et al* followed up 136 patients with right ventricular infarction and found a close correlation between ST segment elevation in the right precordial lead V4R and a worse in hospital course of these patients.^{26 27} Little is known, however, of the prognostic implications of any other previously proposed criteria. Thus, from the known transient character of ST segment elevation and the late admission of many patients with inferior myocardial infarction, the prognostic implications of abnormal Q waves often seen in the right precordial leads beyond the acute infarction phase would be of great interest.

We prospectively studied 200 consecutive patients with acute inferior myocardial infarction to assess the diagnostic efficiency of 10 previously proposed electrocardiographic criteria using abnormal Q waves and ST segment abnormalities in the right precordial and inferior leads in detecting right ventricular infarction compared with haemodynamic measurements and findings on, coronary angiography, technetium 99m-pyrophosphate scanning, and necropsy. We also determined their prognostic implications during the stay in hospital and three years of follow up.

Patients and methods

PATIENTS

From August 1985 to January 1990, we studied 200 consecutive patients with acute inferior myocardial infarction, which was diagnosed from the presence of typical chest pain lasting >30 minutes, an ST segment elevation of >0.1 mV in two or more leads of II, III, and aVF, and a rise in creatine kinase activity above twice normal values (>140 U/l) within the 24 hours after admission. There were 153 men and 47 women; their ages ranged from 35 to 91 years, with a mean of 61.5(6) years. Thirty three patients had a history of myocardial infarction (anterior/lateral infarction, 21; posterior infarction; seven; inferior infarction; five). Six patients had a history of cardiac failure (New York Heart Association class III or IV).

After inclusion in the study 71 patients met the criteria^{28 29} for thrombolysis: they had had infarct symptoms lasting six or less hours, they were 75 or under, they had given their informed consent, and they had no contraindications for thrombolysis including having poorly controlled hypertension (systolic pressure >180 mm Hg or diastolic >110 mm Hg), active bleeding, recent surgery or significant trauma, any cerebrovascular accident, or neoplasm. Patients with cardiogenic shock or cardiac arrest were included only if it was possible to stabilise their condition in the

emergency room and to transfer them to the coronary care unit.

ELECTROCARDIOGRAPHIC ASSESSMENT

The results of standard 12 lead electrocardiography (leads I-III, aVR, aVL, aVF, V1-6) and right precordial surface electrocardiography (V3-6R) were documented immediately after admission to the hospital. In patients receiving thrombolysis electrocardiograms were obtained before drug administration. Six patients with pre-existing bundle branch block (four patients with left bundle branch block, two with right bundle branch block) were included in the study—all but one of these patients had a previous infarction.

ST segment elevation or depression (by ≥ 0.1 mV) was assessed 0.04 s after the J point in all 16 leads; the presence of abnormal Q waves (≥ 0.04 s) was analysed in II, III, aVF, and right precordial leads. Three consecutive QRS complexes were measured using the PQ level as the isoelectric line. All analyses were performed by a cardiologist unaware of the clinical status of the patient; electrocardiograms were classified according to the criteria of the Manhattan code. The following electrocardiographic criteria were additionally studied: ST segment elevation (≥ 0.1 mV) in any of leads V3-6R, Lopez-Sendon criterion (ST segment elevation in V4R > V1-3),¹⁹ abnormal Q waves (≥ 0.04 s) in any of leads V3-4R, Candell criterion (abnormal Q wave and ST elevation in more than one lead in V3-6R),³⁰ and Andersen criterion (ST segment elevation in lead II > 0.1 mV and III/II > 1 mV).¹⁵

DIAGNOSTIC EVALUATION

Right ventricular infarction was diagnosed (a) if there were wall abnormalities, or occlusion (or >90% stenosis) of the right coronary artery proximal to the right ventricular branch, or both, on ventriculography and coronary angiography; (b) if there was necroscopic evidence of such infarction; (c) if there was focal uptake of label on technetium-99m pyrophosphate imaging¹¹; or (d) if right atrial pressure was greater than or equal to pulmonary capillary pressure or showed a strongly non-compliant pattern.¹³

Haemodynamic measurements and technetium-99m pyrophosphate imaging were considered only when performed during acute phase of myocardial infarction (up to 24 hours); results from coronary angiography or from ventriculography were performed during hospital stay. Sensitivity (percentage of patients with right ventricular infarction correctly identified by an electrocardiographic criterion), specificity (percentage of patients without right ventricular infarction and not meeting an electrocardiographic criterion), and diagnostic efficiency of ST elevation in V4R (patients with and without right ventricular infarction correctly identified by an electrocardiographic criterion) were calculated for each of the four diagnostic tests. Overall diagnostic accuracy was calculated by using the results of the first test in each patient according

to the above sequence. This included findings at necropsy in 18 patients, angiographic and ventriculographic findings in 112 patients, results from technetium-99m pyrophosphate imaging in 37 patients, and haemodynamic findings in 20 patients. In 88% of the patients with at least two diagnostic tests diagnostic findings were similar. Thirteen patients in whom none of the four tests could be adequately performed for different reasons (early death, technical reasons) were excluded from further analysis.

PROGNOSTIC EVALUATIONS

The in hospital course was determined in all patients in terms of mortality and the presence of major in hospital complications, including ventricular fibrillation, sustained ventricular tachycardia (>30 s or causing haemodynamic intolerance), cardiogenic shock, myocardial rupture, third degree atrioventricular block, and the need for external or permanent cardiac pacing for other bradyarrhythmias. During the first year after discharge prognostic evaluation included death, fatal or non-fatal myocardial infarction, and the need for pacemaker implantation and for coronary revascularisation.

STATISTICAL ANALYSIS

All pooled data are expressed as means (SD). Differences between groups were analysed using the standard χ^2 test, the non-paired *t* test, and one way analysis of variance whenever appropriate. All tests of significance were two tailed and used a significance level of 5%.

Results

Overall, 106 out of 187 patients (57%) had right ventricular infarction according to findings on coronary angiography, ventriculography, and scintigraphy.

DIAGNOSTIC ACCURACY OF SINGLE AND COMBINED ELECTROCARDIOGRAPHIC CRITERIA FOR RIGHT VENTRICULAR INFARCTION

Table 2 summarises the prevalences of the 10 electrocardiographic criteria in the 187 patients. ST segment elevation in any of the

right precordial leads was observed in 41–55% of patients but was present in only six out of 33 patients (18%, $P < 0.001$) admitted late (>12 hours after the onset of symptoms). The prevalence of abnormal Q waves increased from 51 out of 154 patients (33%) to 18 out of 33 (55%, $P < 0.05$) when patients with early and late admission were compared. Combined electrocardiographic criteria for right ventricular infarction were met by 43–53% of patients when using the right precordial leads, and by 91% of patients when ST segment elevation in leads II and III was used for calculation (table 2).

Table 2 also shows the diagnostic power of the 10 electrocardiographic criteria. Positive predictive values were highest when ST segment elevation ≥ 0.1 mV in lead V4R, or in any of leads V3–6R, was considered (85%). Diagnostic accuracy did not further improve when the extent of ST segment elevation was considered using any cut off point from 0.05 mV to 0.2 mV. Abnormal Q waves in the right precordial leads showed a higher diagnostic specificity (>90%), but sensitivity was low (58–59%), mainly because most patients were admitted early after the onset of symptoms. In the 33 patients admitted late after the onset of symptoms abnormal Q waves had a sensitivity of 95% and a specificity of 93% for showing right ventricular infarction. In the presence of inferior myocardial infarction none of the combined electrocardiographic criteria for evidencing right ventricular infarction was superior to right precordial ST segment elevation or abnormal Q waves alone (table 2).

Diagnostic accuracy of ST segment elevation and abnormal Q waves was not altered in the small subgroup of patients with a history of myocardial infarction, pre-existing bundle branch block, or heart failure.

CLINICAL AND PROGNOSTIC IMPACT OF SINGLE AND COMBINED ELECTROCARDIOGRAPHIC CRITERIA FOR SHOWING RIGHT VENTRICULAR INFARCTION

During the time in hospital 38 of the 200 patients (19%) with acute inferior myocardial infarction died. Ninety four patients (47%) suffered major complications, including cardiogenic shock (31 (16%)), ventricular fibrillation (31 (16%)), sustained ventricular tachycardia (24 (12%)), second degree Mobitz type and third degree atrioventricular block (28 (14%)), pacing requirement (22 (11%)), and myocardial rupture or tamponade (nine (5%)).

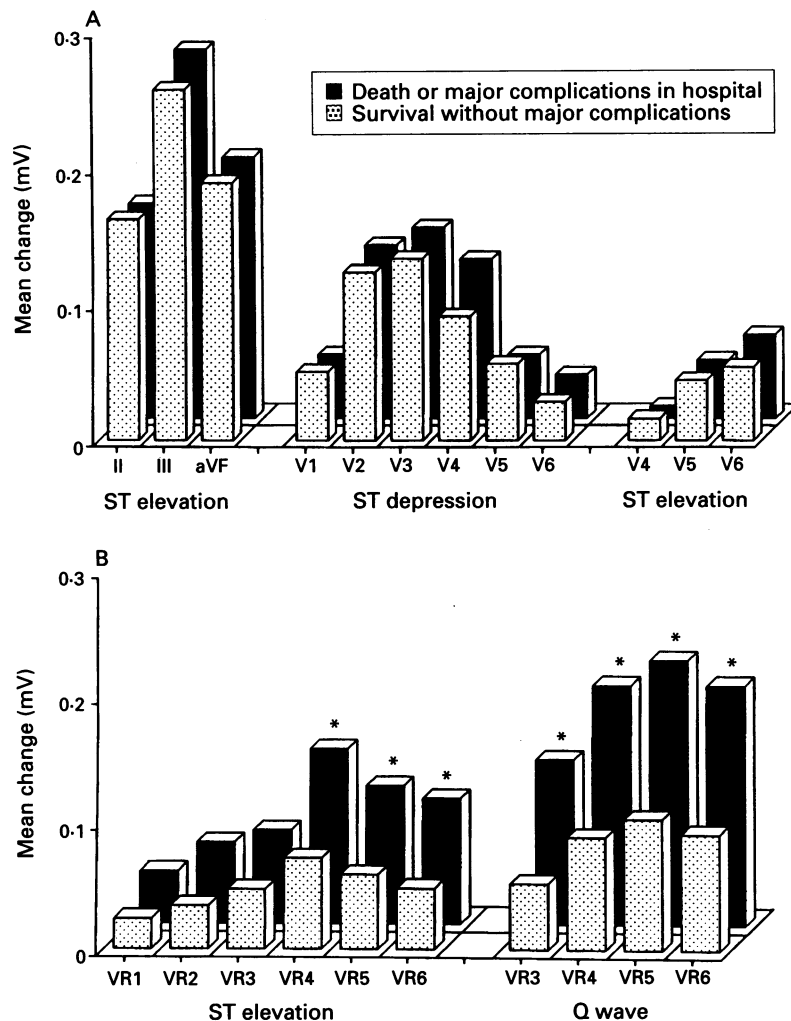
The figure shows the severity of ST segment elevation or depression and of abnormal Q waves in the 15 electrocardiographic leads according to outcome in hospital. Outcome was significantly worsened by a greater ST segment elevation and especially by deeper abnormal Q waves in leads V3–6R. ST segment elevation or depression or abnormal Q waves in the standard leads were not useful in distinguishing patients with and without in hospital complications.

In univariate analysis ST segment elevation ≥ 0.1 mV in the right precordial leads

Table 2 Prevalence and diagnostic efficiency of different electrocardiographic criteria for right ventricular infarction in one hundred and eighty seven patients with acute inferior myocardial infarction

Electrocardiographic criterion	Prevalence (No of patients (%))	Sensitivity* (No of patients (%))	Specificity* (No of patients (%))	Positive predictive value (no of patients (%))
<i>ST segment elevation in right precordial leads V3–6R</i>				
V3R (≥ 0.1 mV)	77 (41)	64 (63)	72 (86)	136 (74)
V4R (≥ 0.1 mV)	101 (54)	88 (89)	70 (83)	158 (85)
V5R (≥ 0.1 mV)	101 (54)	81 (80)	68 (81)	149 (81)
V6R (≥ 0.1 mV)	97 (52)	80 (79)	68 (81)	148 (80)
V4–6R (≥ 0.1 mV)	103 (55)	92 (91)	66 (79)	158 (85)
<i>Abnormal Q wave in right precordial leads</i>				
V4R (> 0.04 s)	67 (36)	59 (58)	78 (93)	137 (74)
V3–4R (> 0.04 s)	69 (37)	60 (59)	77 (92)	143 (77)
<i>Combined electrocardiographic criteria</i>				
Lopez-Sendon criterion ¹⁹	99 (53)	88 (87)	77 (92)	165 (89)
Candell criterion ²⁰	62 (33)	54 (54)	7 (92)	131 (71)
Andersen criterion ¹⁵	170 (91)	96 (95)	11 (13)	107 (58)

* Based on 187 patients who had complete diagnostic test results or in whom necroscopic findings were available.



(A) Mean ST segment changes in leads II, III, aVF, and the left precordial leads V1-6 and (B) mean ST elevation and abnormal Q waves in right precordial leads V1-6R according to whether patients died or had major complications in hospital. Total number of patients is 187.

* $P < 0.05$.

(V4-6R) predicted a 6.2-times higher in hospital mortality ($P < 0.001$) and a 2.3-times higher rate of major in hospital complications ($P < 0.01$) (table 3). Prognostic relevance was also shown for the presence of abnormal Q waves in the right precordial leads V3-4R (mortality increase, 2.3-times, $P < 0.01$;

Table 3 Univariate analysis of mortality and incidence of major complications during stay in hospital for acute inferior myocardial infarction as stratified by electrocardiographic criteria

Electrocardiographic criterion	Mortality (%) when criterion:		Incidence of major complications (%)† when criterion:	
	Present	Absent	Present	Absent
<i>ST elevation > 0.1 mV in right precordial leads</i>				
V3R	30	12*	62	34**
V4R	31	6**	64	28**
V5R	31	5**	64	29**
V6R	32	5**	65	28**
V4-6R	30	5**	61	30**
<i>Q wave in right precordial leads</i>				
V4R	30	13*	65	37**
V3-4R	30	13*	66	36**
<i>Combined criteria</i>				
Candell criterion ³⁰	32	10*	60	37**
Lopez-Sendon criterion ¹⁹	31	5**	62	30**
Andersen criterion ¹⁵	20	11	48	33

†Cardiogenic shock, ventricular fibrillation or sustained tachycardia, second or third degree atrioventricular block, severe bradycardia, pacing required, myocardial rupture.

* $P < 0.01$, ** $P < 0.001$ (univariate analysis).

major complications, 1.8-times, $P < 0.01$). Mortality was highest in patients who met the Candell criterion; this criterion, however, missed many patients with a worse prognosis who presented only with ST segment elevation or abnormal Q waves. None of the combined criteria showed overall prognostic superiority (table 3). Multivariate analysis showed that the prognostic implications of ST segment elevation (mortality, $P = 0.0002$; major complications, $P = 0.0001$) and abnormal Q waves (mortality, $P = 0.0293$; major complications, $P = 0.001$) were independent of clinical variables, such as age, sex, size of myocardial infarction, prehospital complications, thrombolysis, and history of myocardial infarction.

During the first year after discharge from hospital, cardiac death (7% v 6%), sudden cardiac death (5% v 3%), reinfarction (17% v 10%), and need for revascularisation such as bypass grafting or balloon angioplasty (28% v 28%) were similar in patients with and without right ventricular infarction during acute inferior myocardial infarction. The need for permanent pacing increased 5-6 fold in the presence of ST segment elevation or abnormal Q waves.

Discussion

Our study shows that both ST segment elevation and abnormal Q waves in the right precordial leads are of diagnostic and prognostic value when observed during the first 24 hours after the onset of symptoms of infarction. Although right precordial ST segment elevation was a sensitive and specific marker of right ventricular infarction in the early phase of infarction, abnormal Q waves were superior in patients admitted more than 12 hours after the onset of symptoms. Presence of any of the two criteria and especially the combination of both was associated with a worse in hospital prognosis. Previously proposed combined electrocardiographic criteria were not better diagnostically or prognostically in patients with acute inferior myocardial infarction.

Right ventricular infarction complicates acute inferior myocardial infarction in 19-51% of patients.³¹⁻³³ Its early recognition is clinically relevant because of the increased incidence of major complications in these patients,^{4,5,31} subsequently leading to a higher in hospital mortality.³³⁻³⁷ During recent years an increasing number of electrocardiographic criteria has been proposed to show right ventricular infarction to overcome the logistical and methodological problems and the time delay inherent in the use of more complex tests, such as cardiac angiography,^{2,38} scintigraphic imaging,⁷⁻¹¹ and haemodynamic measurements.^{5,6,12,13} The most extensively studied electrocardiographic criterion for right ventricular infarction is ST segment elevation in lead V4R, which is effective in diagnosing acute right ventricular infarction,^{18,23,24,26,27,30,39} as well as predicting prognostic outcome in patients with acute inferior myocardial infarction.^{26,27}

To improve diagnostic and prognostic accuracy still further, however, an increasing number of additional electrocardiographic criteria using ST segment elevation of different extent and in different right precordial leads, as well as abnormal Q waves and a combination of both, has been proposed (table 1). Thus, the sensitivity of ST segment elevation was increased when its presence in any of leads V4–6R was considered¹⁶ or a smaller elevation was used—for example, 0.05 mV.^{19 22 23} Owing to a lower specificity, however, these studies failed to increase overall diagnostic efficiency. To improve specificity, Morgera *et al* and Lopez-Sendon *et al* proposed using the presence of abnormal Q/QS waves in the right precordial leads for diagnosing right ventricular infarction.^{19 23} This criterion was considered to be of particular interest in patients admitted late after the onset of infarction symptoms because ST segment elevation is transient in most patients.^{18 24} In the only three studies looking at abnormal Q waves in the right precordial leads sensitivity (37–94%) and specificity (59%–100%) varied widely,^{14 19 23} but these studies were limited by including fewer than 60 patients with right ventricular infarction. More recently, Andersen *et al*, reported the value of another electrocardiographic criterion using the ratio of ST segment elevation in leads II and III to show right ventricular infarction.¹⁵

Apart from ST segment elevation in lead V4R, however, data on the diagnostic accuracy of the other proposed electrocardiographic criteria are rare and have not been evaluated in a prospective and comparative study in the same patient population; also data are not available on the prognostic implications of these criteria. We therefore assessed such information in 187 consecutive patients with acute inferior myocardial infarction, in whom a diagnostic work up, including coronary angiography, technetium pyrophosphate imaging, haemodynamic measurements, and findings at necropsy, indicated the presence of right ventricular infarction in 57% of patients. There were only minor differences in the diagnostic and prognostic impact when ST segment elevation either in lead V4R or in any of leads V4–6R was chosen. Overall, diagnostic accuracy was not increased, by selecting any criteria other than 0.05 to 0.2 mV for the extent of ST segment elevation.^{19 22 23} ST segment elevation, however, increasingly failed to show right ventricular infarction when patients were admitted to the hospital late after the onset of infarction symptoms. Because of the development of myocardial necrosis in these patients abnormal Q waves subsequently replaced ST segment elevation. Under these circumstances, therefore, abnormal Q waves were a highly sensitive and specific criterion for right ventricular infarction.

Independently of when they were observed, abnormal Q waves within the first 24 hours after the onset of symptoms were associated with a worse in hospital course. Mortality and complication rate were both doubled. This is

somewhat lower than the prognostic impact previously reported for ST segment elevation in lead V4R^{26 27} and, as shown in this study, in any of leads V4–6R. The presence of abnormal Q waves may, however, be particularly helpful when patients are admitted late after the onset of symptoms and they no longer have ST segment elevation. Therefore abnormal Q waves and ST segment elevation should be considered as complimentary rather than competitive criteria, both carrying prognostically relevant information.

All combined electrocardiographic criteria proposed to improve the diagnostic accuracy of right precordial ST segment elevation^{15 19 28} failed to do so in this study. When compared with previous work, this lack could be because we included only patients with inferior myocardial infarction,¹⁹ because we could not confirm previously reported results,¹⁵ or because the proposed criterion was too restrictive, resulting in high specificity but low sensitivity.³⁰ Similarly, none of these criteria was better overall superiority in predicting prognosis.

Long-term follow up over three years showed a high incidence of cardiovascular events, but none of the above mentioned criteria for diagnosing right ventricular infarction was helpful in stratifying the patient's outcome after discharge from hospital, except for the need for permanent pacemaker implantation.

LIMITATIONS OF OUR STUDY

ST segment elevation in the right precordial leads V3–6R is represented by a rightward and anteriorly oriented vector; thus leftward ST segment deviation as seen in the lateral left precordial leads for a lateral infarction may cancel out the ST segment elevation in the right precordial leads. In our study only 36% of patients were given thrombolysis, which is similar to the percentages in previous reports.^{28 29} Thrombolysis was not relevant when the diagnostic and prognostic implications of different criteria for right ventricular infarction were compared.

CONCLUSION

In acute inferior myocardial infarction ST segment elevation in leads V4–6R and abnormal Q waves in the right precordial leads should be considered as complimentary, rather than competitive, criteria for diagnosing right ventricular infarction during the 24 hours after the onset of symptoms. ST segment elevation during the acute phase of infarction and abnormal Q waves more than 12 hours after the onset of pain both carry important prognostic information for the in hospital course in these patients. The extent of ST segment elevation, as well as combined electrocardiographic criteria, do not further increase the overall diagnostic accuracy and prognostic impact of these criteria. Assessment of a right precordial electrocardiogram should be routine in all patients presenting with acute inferior myocardial infarction.

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